FORMATION OF SINOITE IN EL CHONDRITES BY IMPACT MELTING Alan E. Rubin, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA.

Silicon oxynitride (sinoite; Si_2N_2O) has been identified in eight EL6 chondrites where it occurs as ≤200-µm-size euhedral, lath-like grains associated with metallic Fe-Ni and enstatite (e.g., [1-3]). Although the origin of sinoite has been controversial, recent papers (e.g., [4]) have advocated a metamorphic origin. However, I have identified ~10-200-µm-size subhedral and euhedral grains of twinned, optically zoned sinoite associated with euhedral enstatite and euhedral graphite within impact-melted portions of QUE94368, the first EL4 chondrite. These observations suggest that sinoite formed by crystallization from a melt, not by thermal metamorphism. The presence of sinoite in several EL6 chondrites implies that these rocks were partly impact melted. The S2 shock stages and recrystallized textures of these EL6 chondrites suggest that, after impact melting, the rocks were annealed, then very weakly shocked [5].

Although laboratory synthesis of silicon oxynitride was achieved by heating metallic Si with fine-grained silica in a nitrogen atmosphere at 1450°C [6], the origin of sinoite in meteorites has been controversial. Herndon and Suess [7] and Sears [8] suggested that sinoite formed by condensation at high temperatures and pressures in the solar nebula from a gas of solar composition, but other thermodynamic calculations [9,10] disputed this. Petaev and Khodakovsky [11] and Fogel et al. [12] proposed that sinoite formed metamorphically; Muenow et al. [4] suggested that sinoite formed at EL6 metamorphic temperatures (i.e., ~950°C; [4,13]) over geologic time scales under conditions wherein Si-bearing metallic Fe-Ni acted as a catalyst.

Rubin et al. [5] found that all known EL6 chondrites are shock stage S2 and suggested that many EL6 chondrites (including some of those containing sinoite) are not simple metamorphic rocks. Many appear to have experienced moderate-to-strong degrees of shock (and, in some cases, impact melting) followed by annealing. After annealing, they were shocked again to S2 levels. Characteristic petrographic features of *unannealed* enstatite chondrite impact-melt breccias (e.g., Abee) include the presence of euhedral laths of graphite as well as euhedral grains of enstatite surrounded by kamacite [14].

The 1.2-g QUE94368 enstatite chondrite, originally classified as E5 [15], should be reclassified as the first EL4 chondrite. Characteristics indicative of petrologic type 4 include its moderately distinct chondritic structure and the presence of a millimeter-size porphyritic chondrule containing 20-100-µm-size forsterite grains poikilitically enclosed in enstatite phenocrysts. (Olivine is absent in type-5 and -6 enstatite chondrites.) Characteristics indicating that QUE94368 is an EL chondrite include kamacite with relatively low Si (0.5-0.7 wt.%) [15], the absence of niningerite, the occurrence of rare grains of ferroan alabandite, and the presence of chondrules averaging ~520 µm in apparent diameter (n=15). The latter value is very close to the average apparent diameter of chondrules in the ALH85119, MAC88136 and PCA91020 EL3 chondrites (~550 µm; [16]) and appreciably greater than that of EH3 chondrules (~220 µm; [17]).

The occurrence of olivine and enstatite with undulose extinction in QUE94368 indicates that the rock is shock stage S2, corresponding to an equilibration shock pressure of ~5 GPa [18-20; 5], as in EL5 and EL6 chondrites [5].

QUE94368 is an impact-melt breccia. It contains abundant euhedral laths of graphite and numerous grains of euhedral enstatite surrounded by kamacite. There are also ~10-200-µm-size subhedral and euhedral grains of twinned, optically zoned sinoite adjacent to euhedral enstatite grains and surrounded by kamacite and goethite (formed from kamacite by terrestrial weathering). The kamacite in these regions of QUE94368 formed by solidification of a metal-rich liquid after impact melting. The presence of sinoite within a type-4 chondrite mitigates against the metamorphic model for sinoite formation. The presence of euhedral grains of sinoite within impact-melted portions of QUE94368 indicate that sinoite crystallized from a melt.

Nitrogen in enstatite chondrites probably occurs within lattice defects in sulfide phases [4]. Dynamic high-temperature mass-spectrometric analysis of EH and EL chondrites indicates that N is released between ~950 and 1080°C [4]; this interval corresponds approximately to the temperature of the metallic-Fe-Ni-sulfide cotectic. It seems likely that sinoite in EL chondrites formed in a manner analogous to the laboratory synthesis of silicon oxynitride [6]: during impact-melting of EL material, N was released from sulfide and reacted with reduced Si dissolved in the metallic Fe-Ni melt and with fine-grained (or molten) silica derived from the silicate fraction of the EL chondrite assemblage. Although much N probably escaped during the impact event, I speculate that sufficiently high N partial pressures to permit sinoite crystallization were achieved in temporary, melt-filled cavities constructed from unmelted EL material.

Because bulk N is higher in sinoite-bearing EL6 chondrites (~650-780 µg/g) than in non-sinoite-bearing EL6 chondrites (~50 µg/g) or in EH chondrites (none of which contain sinoite) (~180-430 µg/g) [21], I suggest that sinoite formation is restricted to impact-melted enstatite chondrites that initially possessed abundant bulk N.

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